OPTIMIZATION OF THE DECHIRPER FOR ELECTRON BUNCHES OF ARBITRARY LONGITUDIAL SHAPES*

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Abstract

Dechirper is a passive device composed of a vacuum chamber of two corrugated, metallic plates with an adjustable gap. By introducing a small offset in the dechirper with respect to the reference axis, one might generate transverse wakefields and use the dechirper as a deflector. Understanding the interactions between electron beams of various longitudinal shapes with the wakefields generated by the dechirper is important to assess the feasibility of the dechirper for use as a deflector. Recently, using a set of alpha-BBO crystals, shaping of laser pulses and electron bunches on the order of ps is tested at the Injector Test Facility (ITF) of Pohang Accelerator Laboratory (PAL). Furthermore, we have investigated propagation of electron bunches of arbitrary longitudinal shapes through the dechirper. In the numerical simulations, we observed that the arbitrary electron beams were successful deflected except for lethal beam shape problems. Hence, in this work, we study optimization of the dechirper for electron bunches of arbitrary longitudinal shapes, using analytical theory and numerical simulations with the ASTRA and ELEGANT codes.

INTODUCTION

The dechirper is consistently studied as the beam energy chirp control and passive linearizer by experts of LBNL, SLAC, PAL BNL, and SINAP, etc… Recently, Heung-Sik Kang of PAL (Pohang Accelerator Laboratory) proposed to use the dechirper as a deflector. When the beam has an offset from the center of the dechirper, it acts like a deflector.

Not only longitudinal wakefield, but also quadrupole and dipole wakefield are major influences on beam when beam have offset with respect to dechirper.

Figure 1 shows geometric parameters of the dechirper: gap between two plates g=2a, corrugation period p, corrugation gap t, the corrugation depth (h), and the width of plate w. Since each plates have motors, it can adjust the gap to 5-28 mm.

When dechirper is used as a deflector, there are several problems. First, non-linearly deflected beam is different from RF deflector which deflects the beam linearly. Second, gradient of voltage kick that the particles experienced, is negative. This long beam case makes analysis of longitudinal beam shape much difficult and require distinctive methods.

This study is the dechirper as a deflector to measure arbitrary longitudinal structure of electron bunch.

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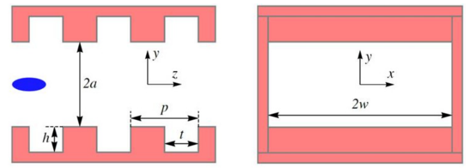

Figure 1: Geometry of dechirper parameters. Side (left) and front view (right) of the dechirper.

Near the axis and assuming $w \gg g$, the transverse wake between two particles can be written in terms of dipole and quad wake function $w_d(s), w_q(s)$ as

$$W_y(s) = W_d(s)y_l + W_q(s)y_t\,, \quad (1)$$

$$W_x(s) = W_q(s)(x_l - x_t)\,, \quad (2)$$

with y_l, x_l, the offsets of the leading particle and y_t, x_t, the offsets of the trailing one [1]. Where s is distance between leading and trailing one. Using transverse wake, voltage of each particle experienced can calculate as

$$V_y(t) \cong y_l \int_{-\infty}^{t} W_d(t-t') * I(t')dt'. \quad (3)$$

Where I is longitudinal distribution [2]. At Eq. (3), the quadrupole wake (W_q) terms are ignored to simplify the Eq. (2). Later, introducing of spread distribution includes the quadrupole effect.

SIMULATION TEST FOR DECHIRPER AS A DEFLECTOR

Figure 2 shows the layout of the simulation test for dechirper as a deflector which consists of two S-band Accelerating structure (L0a, L0b), a 1-meter long dechirper, three quads and screen is 3 m far from the dechirper.

There are two kinds of beam used, first beam is pencil beam which transversal beam distribution is small enough to ignore. Standard deviation of X and Y plane (σ_x and σ_y) are 2.8×10^{-7}. Second beam is fat beam which has fat transverse distribution and standard deviation of X and Y plane (σ_x and σ_y) are 2.8×10^{-4}. These two beams have same longitudinal distribution as uniform-ellipse, and 200 pC of bunch charge.

Table 1 parameters are used and Fig. 3 is results of two different beams simulation.

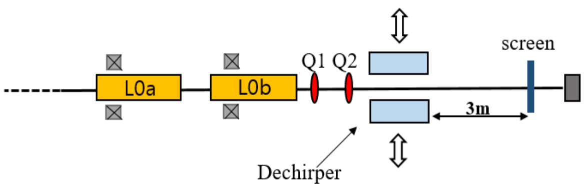

Figure 2: Layout of the simulation.

Table 1: Dechirpir's Geometry Parameters

Parameters	value
a	3mm
p	0.5 mm
h	0.6 mm
t	0.3 mm

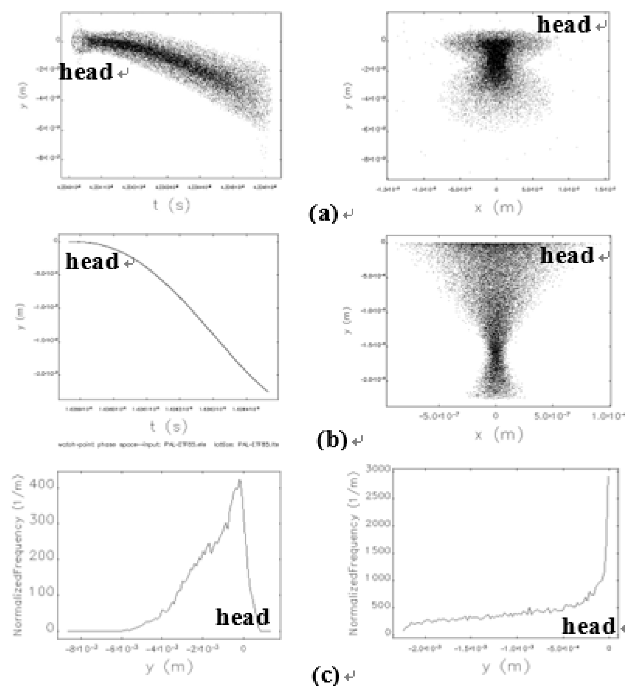

Figure 3: ELEGANT simulation results, t-y plane (left of (a) and (b)) and x-y plane (right of (a) and (b)) projection on screen. (a) Fat beam. (b) Pencil beam. (c) y-directional distribution on screen of fat beam (left) and pencil beam (right)

RECONSTRUCTION OF THE BEAM CURRENT

Since the screen distribution is only measurable information. Non-linear deflection and unknown longitudinal current distribution of the beam, current reconstruction is proper way by means of iterative process.

Reconstruction method is only valid for pencil beam and requires y-directional distribution of pencil beam $f(y)$. At the beginning of Reconstruction, I_{guess} is normalized by Gaussian distribution of current, but after guessed current I_{guess} is updated as reconstructed current I_{re}. These are steps for reconstruction.

Step 1: Calculate the voltage using given normalized current distribution.

$$V_y(t) \cong y_1 \int_{-\infty}^{t} W_d(t-t')I_{guess}(t')dt' . \qquad (4)$$

Step 2: From the voltage, calculate the y position of each bins.

$$y_2 = R_{34}\frac{qV(t)}{E_0} . \qquad (5)$$

Step 3: Calculate new current distribution.

$$I(t)dt = f(y)dy . \qquad (6)$$

Step 4: Reconstruct with the value from step 1 in terms of current distribution and current distribution from step 3.

$$I_{re} = I_{step.3} + \alpha(I_{step.1} - I_{step.3}) . \qquad (7)$$

And updating the I_{guess} as a reconstructed current I_{re}. When loop is repeated enough, all currents converge to specific values.

Equation (4) calculates the y-directional voltage kick using input current and Eq. (5) is simplified calculation of y position on the screen. Since, I and $f(y)$ are normalized distribution, therefore Eq. (6) should be valid. At last, Eq. (7) is reconstruction of current using previous step1 and step 3 current.

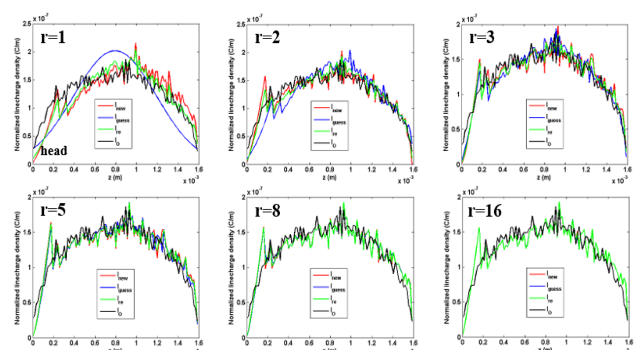

Figure 4: The Reconstruction method outputs. Initial longitudinal beam distribution is uniform-ellipse. r is iteration cycles of reconstruction and I_o is original current.

Figure 4 shows the reconstruction results. After enough repetition cycles of reconstruction, all currents converge to some specific values and average error percent between original current and reconstructed current is less than 1 %.

Spread Distribution

Reconstruction is only for pencil beam case. In order to adopt reconstruction at fat beam, spread distribution is required. Fat beam's y directional distribution on screen (y) is convolution of pencil beam's y directional distribution on screen (y) and spread distribution σ_spread (Eq. (8)).

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$$F(y) = \int_{-\infty}^{y} f(y - y')\sigma_{spread(y')}dy' . \quad (8)$$

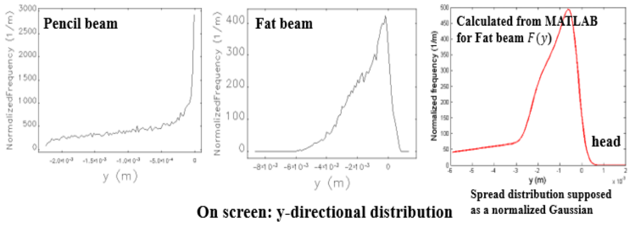

Figure 5: y-directional distribution on the screen. Left is pencil beam, middle is fat beam and right is calculated (y) with assumed as normalized Gaussian of spread distribution.

At Fig. 5, right plot is calculated from MATLAB using supposed spread distribution. This plot looks very similar to original (y).

Experimentally expected spread distribution is following; 1. the beam distribution is measured at screen for Transverse spread, 2. the beam distribution is measured at screen with the dechirper and no offset for quadrupole wake, and 3. the beam distribution is measured at screen with the dechirper and offset.

Estimation of spread distribution is $\sqrt{< y^2 >}$. If spread is known, according to convolution theorem, get $f(y)$ is possible.

Long Beam Case

When beam length is long enough that the voltage kick's gradient is negative, then it isn't monotonic anymore. In this situation, analysis of the beam become much more difficult. It can handle 2-to-1 mapping by dividing z into two regions. At each region, the function has 1–to-1 mapping. Figure 6 is example of long beam cases. It does not affect transverse distribution, but only longitudinal distribution and bunch length.

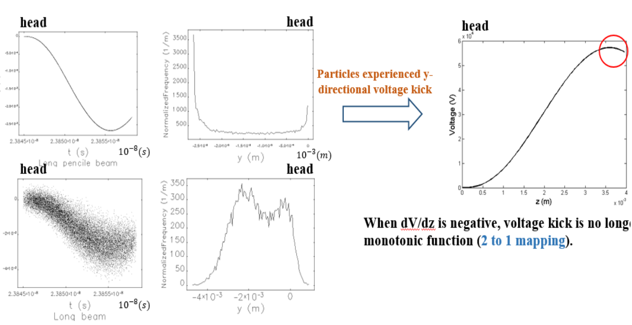

Figure 6: Left pictures are pencil and fat beam side view and y-directional distribution on the screen. Right picture is particles experienced voltage kick.

OPTIMIZATION OF THE DECHIRPER AS A DEFLECTOR

Wakefields are dependent on geometry of the dechirper. Maximizing the dipole wake and minimizing the quadrupole wake are desirable for the dechirper's deflector performance. And total bunch length should be less than the first peak position of dipole wakefield. If not, we will have a long beam case like it is mentioned previously. To avoid the long beam case, it should apply a shorter bunch. If a long bunch has to be measured, changing the dechirper's geometry would be necessary.

Transverse wake functions, W_d and W_q both functions depend on the gap as $\propto a^{-4}$ [3]. The half gap a is adjustable using two different motors on each plate. Except a, other parameters are fixed once a dechirper is installed, but simulation facilitates various structures of the dechirper. The dechirper's calculation assumption is the condition for the corrugated vacuum chamber used as an energy chirp control and linearizer, not as a deflector. Due to this reason, numerical calculation for transverse wakefield for maximizing the performance as a deflector of the dechirper is required.

CONCLUSION

Until now, dechirper is only performed as an energy chirp control and passive linearizer. However, introducing of the beam offset from the center of dechirper makes deflector function of the dechirper feasible. The difference between RF-deflector and the dechirper is linearity. Beam deflection with RF-deflector is almost linear because this device is expensive RF system. But, the dechirper is passive device which deflects the beam nonlinearly using generated wakefield and much cheaper than that RF system.

Since, non-linearity is output of wakefields and current convolution, analysis of the longitudinal beam distribution is hard. Therefore, reconstruction method is one solution for the analysis. Furthermore, this method is invalid only for pencil beam. So as to adopt reconstruction method at fat beam, spread distribution is convenient technique to make fat beam to pencil beam.

Best condition for the decherper's deflector performance, numerical calculation of transverse wakefields is necessary.

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